December 30th (2018)

Inflationary particle production and non-Gaussianity

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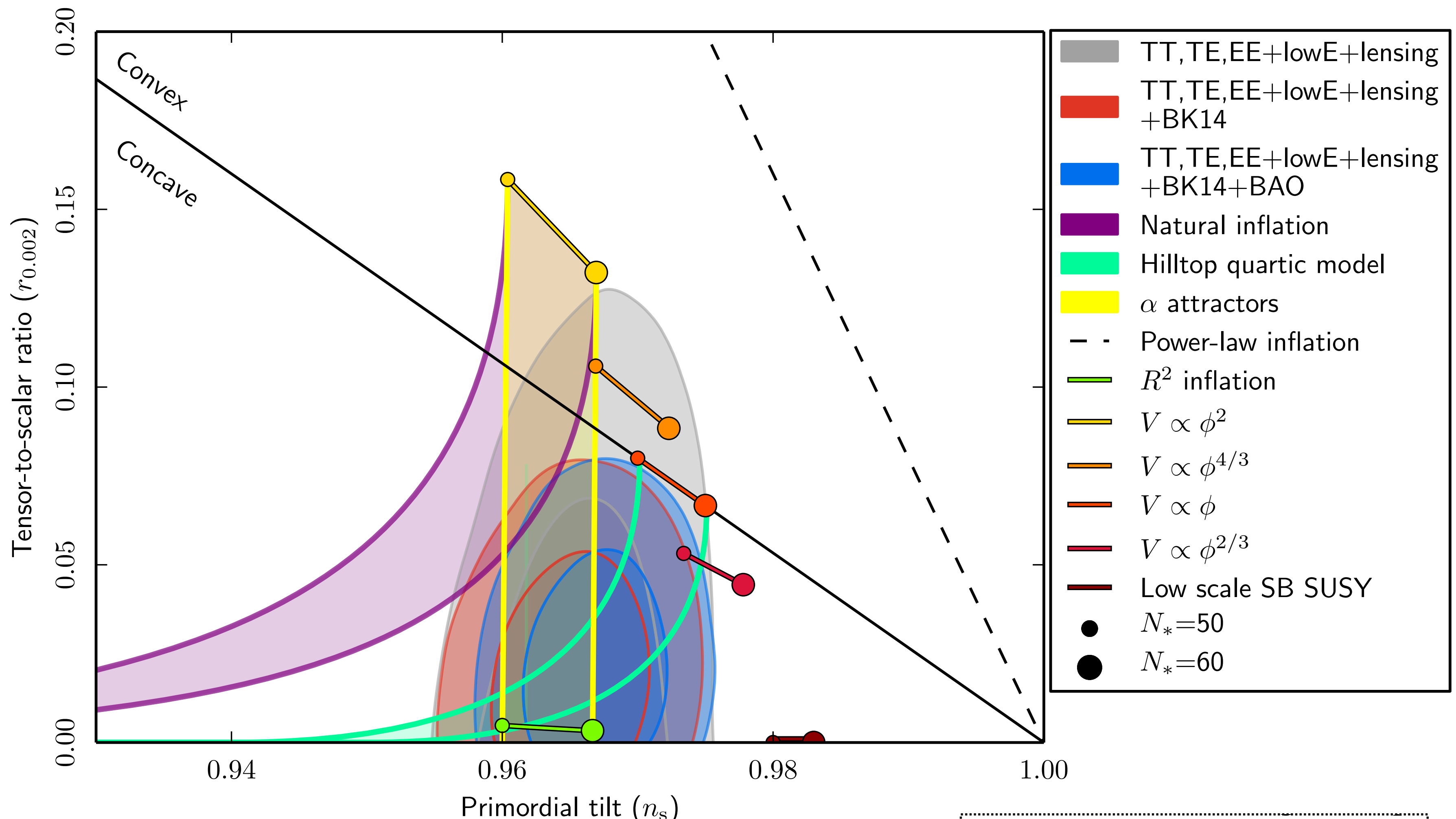
based on: arXiv[the last day of 2018?]

see also Yi Wang, YPW, Jun'ichi Yokoyama, Siyi Zhou JCAP07 068 (2018)

Heavy particles during inflation

Standard single-field inflation with Einstein gravity

PLANCK (2018)

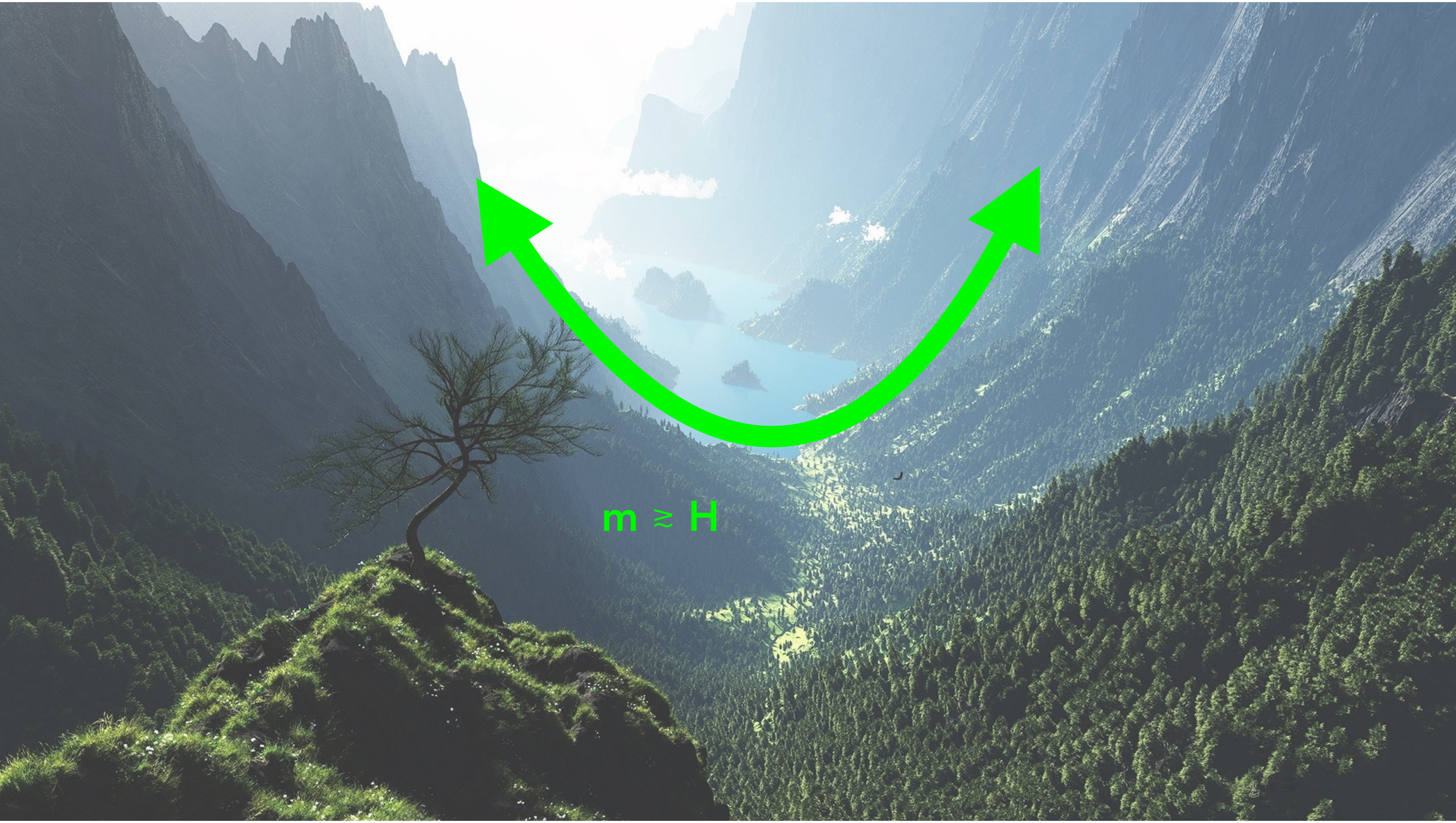


$n_s = 0.9649 \pm 0.0042$ at 68 % CL.

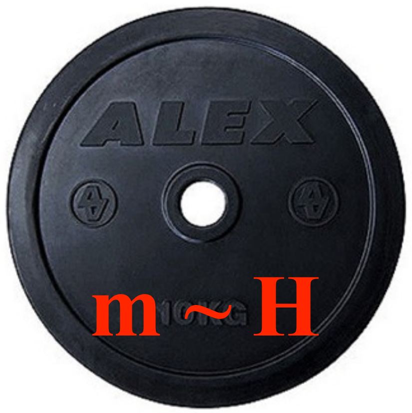
➤ No evidence beyond slow-roll (nor feature in the potential).

UV completion of single-field inflation

UV completion of single-field inflation



The origin of heavy particles



◎ SUSY breaking / SUGRA ?

Baumann & Green [1109.0292]

Yamaguchi [1101.2488]

◎ heavy-lifted SM particles ?

Chen, Wang & Xianyu [1610.06597]

Kumar & Sundrum [1711.03988]

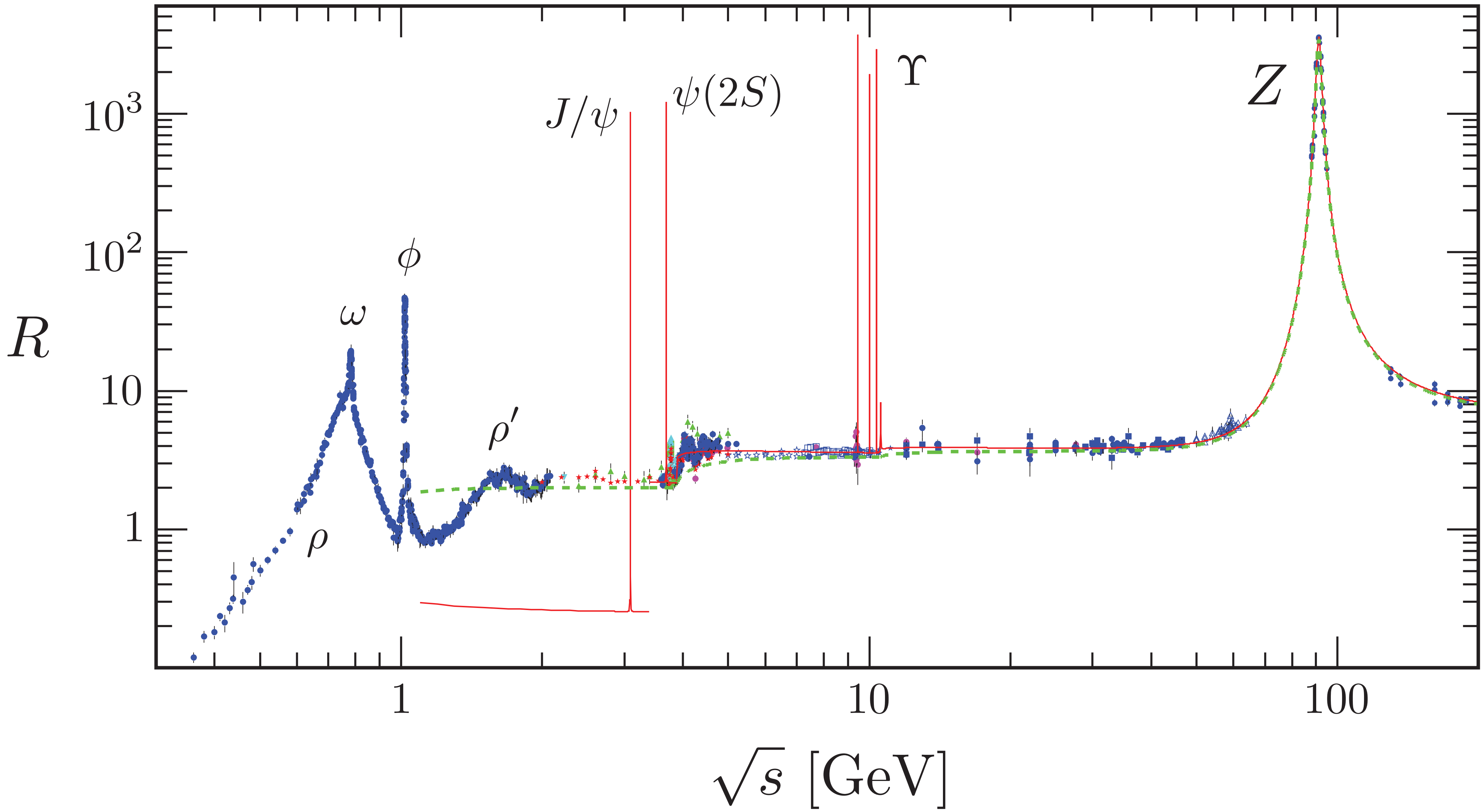
◎ GUT / extra-dim ?

Kumar & Sundrum [1811.11200]

Particle production
& non-Gaussianity

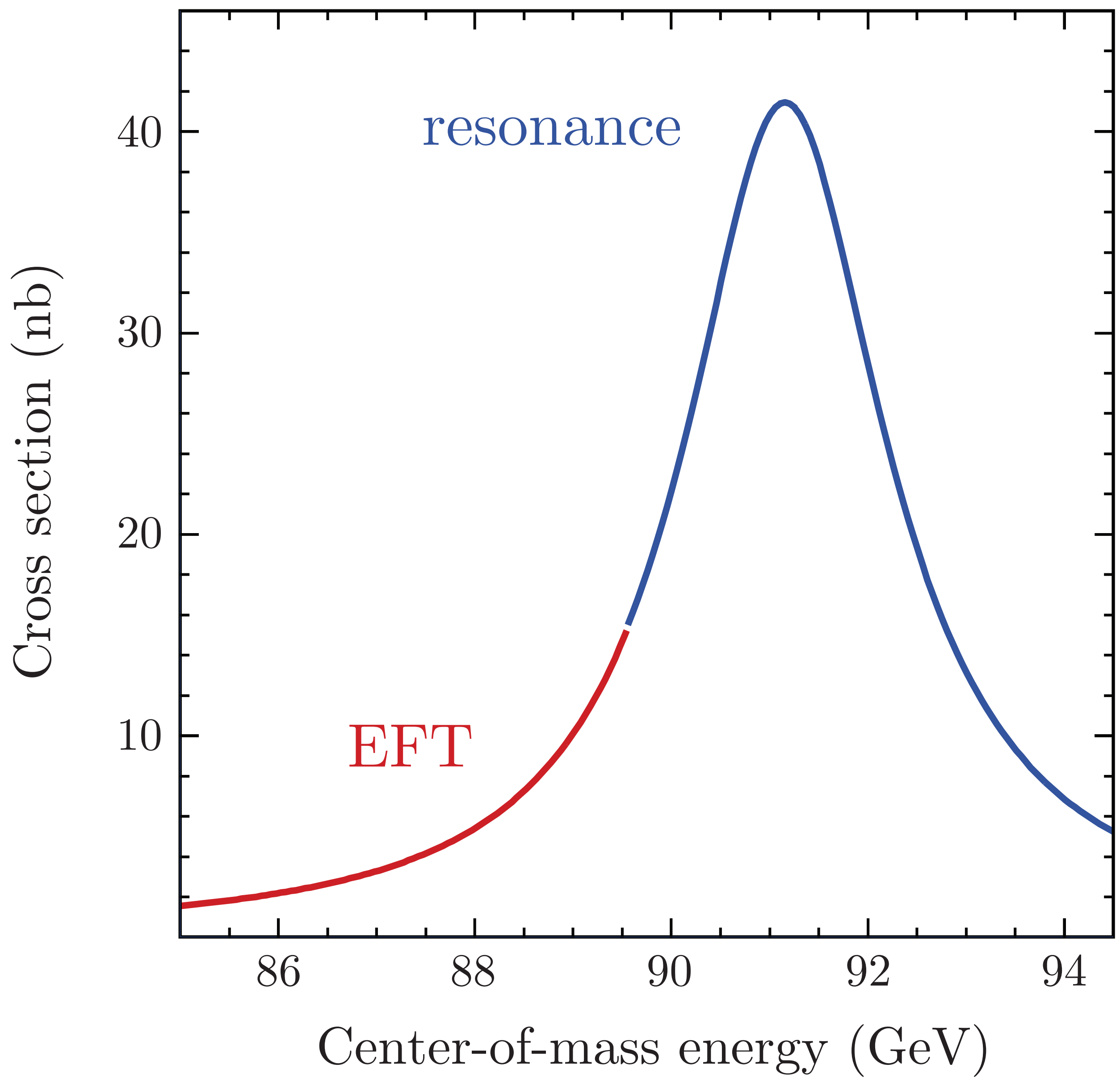
The resonance peaks

Particle Data Group 2018

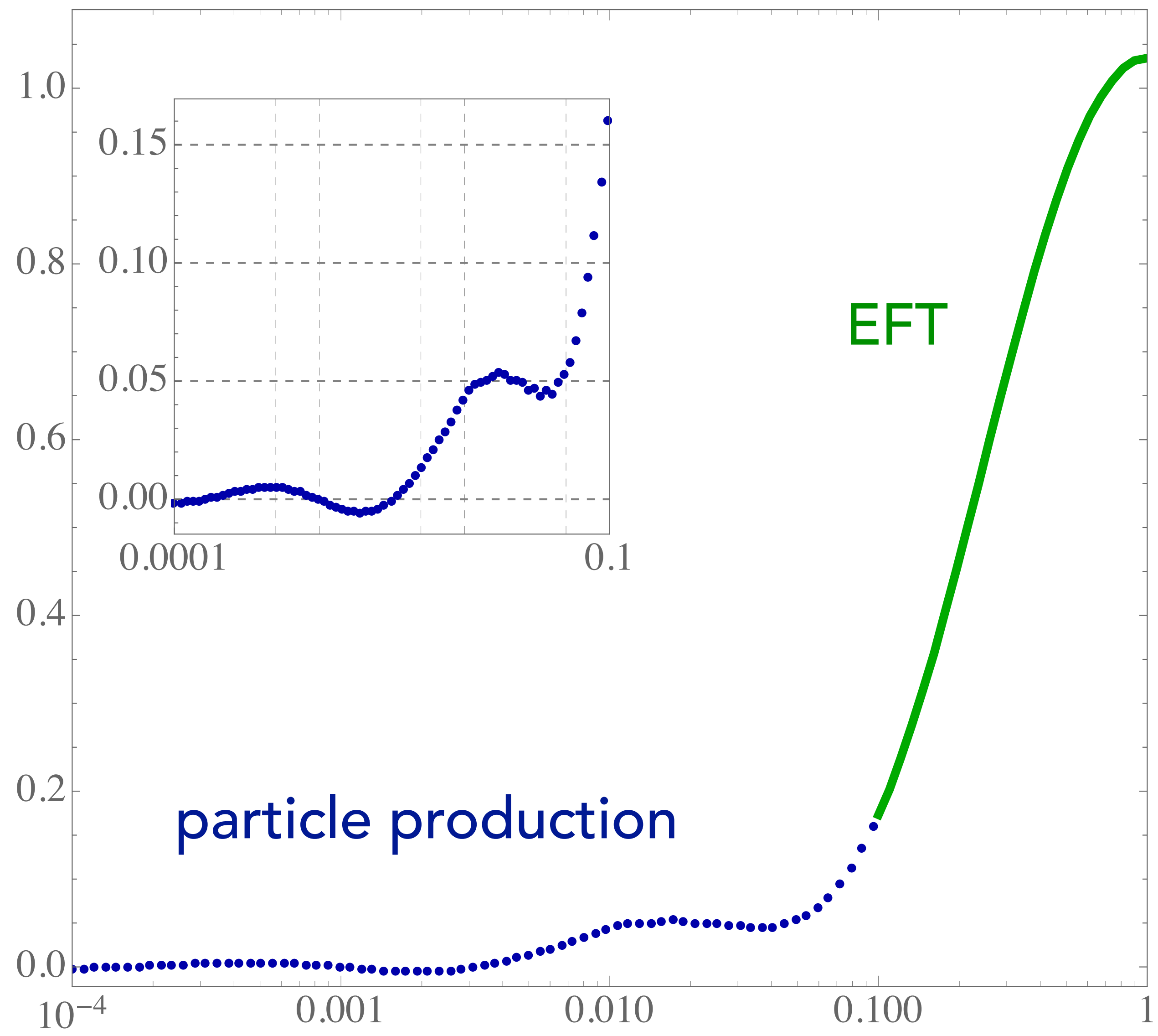


The Z resonance

a slide from Daniel Baumann



The simplest non-Gaussian observable $\langle\zeta^3\rangle$

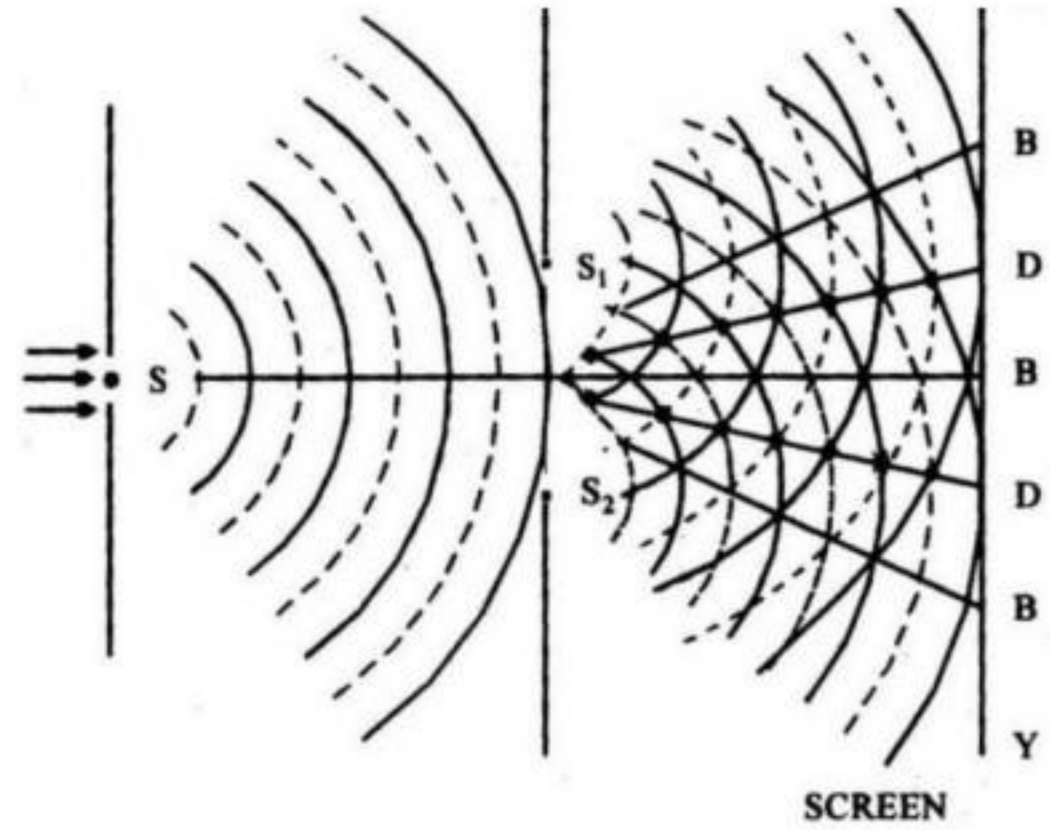


$k_{\rm long}/k_{\rm short}$

wave interference

The source

$$\Psi_1(\vec{r},t) = A_1(\vec{r})e^{-i[\omega t - \alpha_1(\vec{r})]}$$
$$\Psi_2(\vec{r},t) = A_2(\vec{r})e^{-i[\omega t - \alpha_2(\vec{r})]}$$



The intensity

$$I(\vec{r}) = \int dt\ \Psi\Psi^*$$
$$\sim A_1^2 + A_2^2 + 2A_1A_2\cos[\alpha_1 - \alpha_2]$$

credit: physics@TutorVista.com

$$\Psi = \Psi_1 + \Psi_2$$

cosmological quantum interference

Two sources in de Sitter space

$$\zeta(k,\eta) \sim \hat{O}(\mathbf{k})\,\eta^{3/2}$$ analytic waves

$$\sigma(k,\eta) \sim \hat{O}^{+}(\mathbf{k})\,\eta^{\Delta+} + \hat{O}^{-}(\mathbf{k})\,\eta^{\Delta-}$$ analytic + non-analytic waves

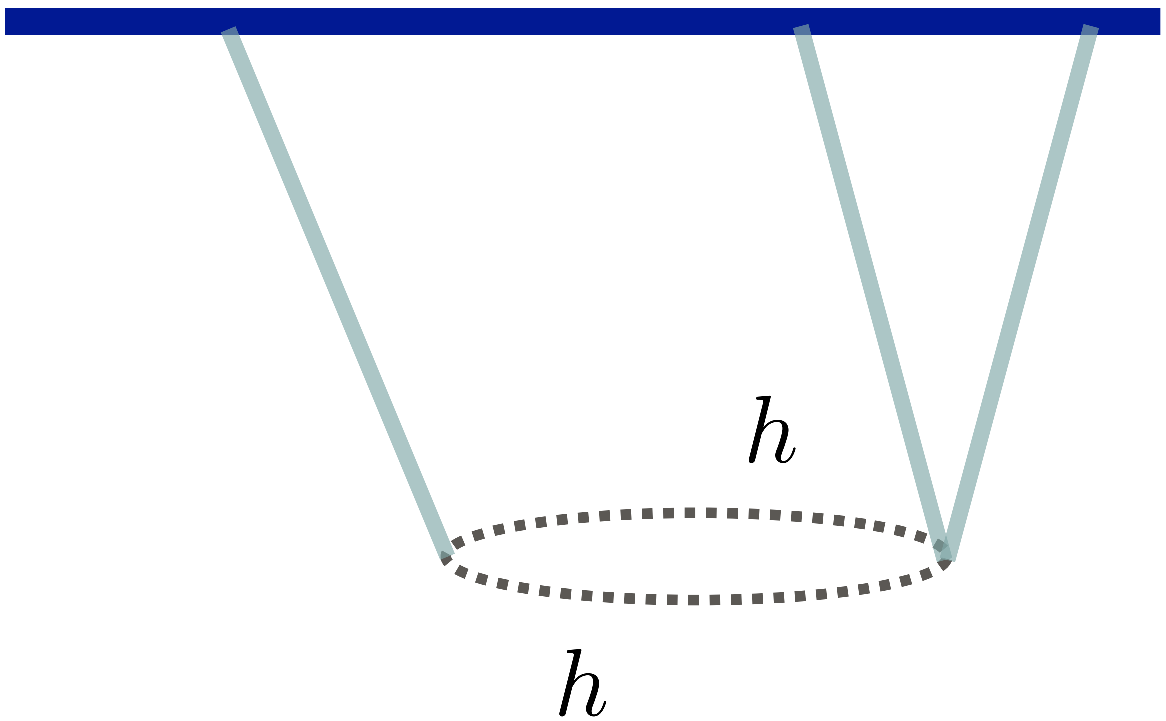
fixed by isometries of dS: $$\Delta^{\pm} = \frac{3}{2} \pm i\sqrt{\frac{m_\sigma^2}{H^2} - \frac{9}{4}}$$

non-analytic effects

The correlation function

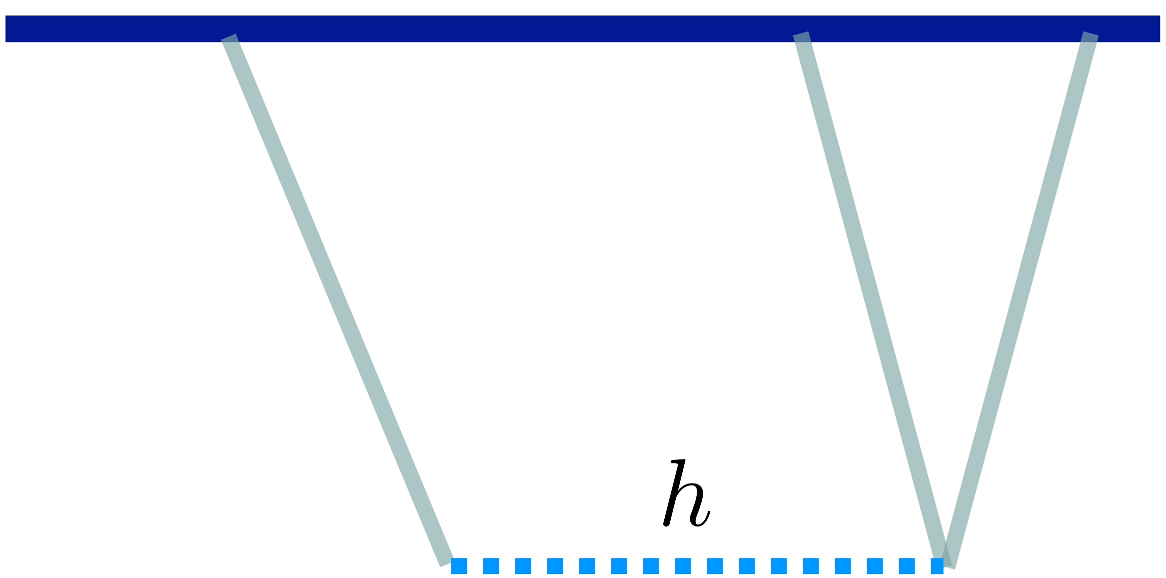
$$\left\langle \hat{Q}[\zeta, \dot{\zeta}, \sigma, \dot{\sigma}] \right\rangle = (\text{non-oscillatory}) + (\text{oscillatory})$$

The signal of Higgs



Chen, Wang & Xianyu [1610.06597]

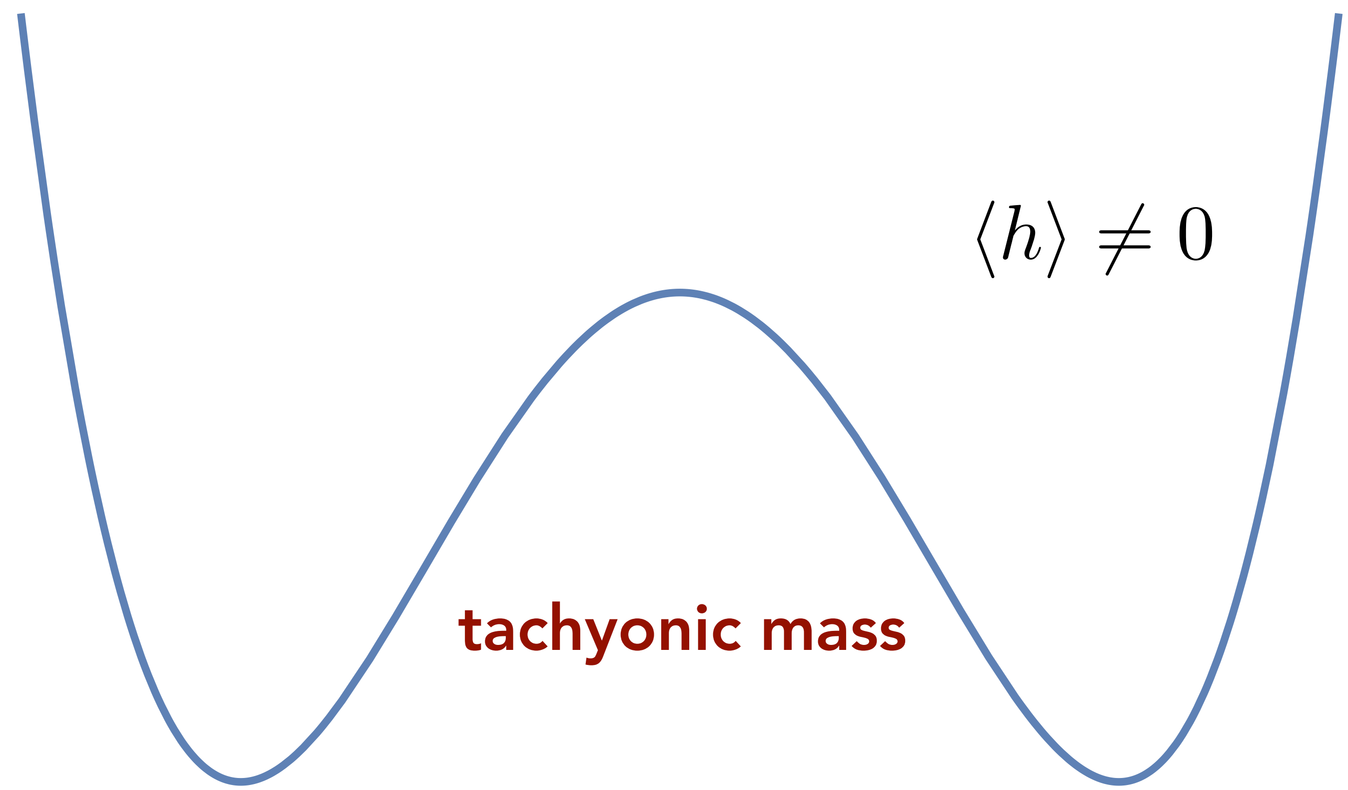
Chen, Wang & Xianyu [1612.08122]



Kumar & Sundrum [1711.03988]

$\Rightarrow$ larger $\quad f_{\rm NL}$

Spontaneous symmetry breaking during inflation



Kumar & Sundrum [1711.03988]

$-\xi R\, h^2$

$-F(\phi, \partial_\mu \phi) h^2$

Heavy-lifting from EFT

Kumar & Sundrum [1711.03988]

(weak-coupling)

$$\mathcal{L}_{\text{int}}^{\text{inf-gauge}} = \frac{c_1}{\Lambda}\partial_\mu\phi(\mathcal{H}^\dagger D^\mu\mathcal{H}) + \frac{c_2}{\Lambda^2}(\partial\phi)^2\mathcal{H}^\dagger\mathcal{H} + \frac{c_3}{\Lambda^4}(\partial\phi)^2|D\mathcal{H}|^2 + \frac{c_4}{\Lambda^4}(\partial\phi)^2 Z_{\mu\nu}^2 + \frac{c_5}{\Lambda^5}(\partial\phi)^2\partial_\mu\phi(\mathcal{H}^\dagger D^\mu\mathcal{H}) + \cdots$$

conclusion for non-Gaussianity

F	Goldstone EFT with $\Lambda \sim 5H$	Goldstone EFT with $\Lambda \sim 10H$	Slow-roll Models with $\Lambda \sim 60H$
h	$1 - 10$	$0.1 - 1$	$0.01 - 0.1$
Z	$0.1 - 1$	$0.01 - 0.1$	$0.001 - 0.01$

Heavy-lifting from broken symmetry

$$\mathcal{L} \supset -\frac{1}{2}\left(1+\frac{h^2}{\Lambda^2}\right)(\partial_\mu \phi)^2 - \frac{1}{2}(\partial_\mu h)^2$$

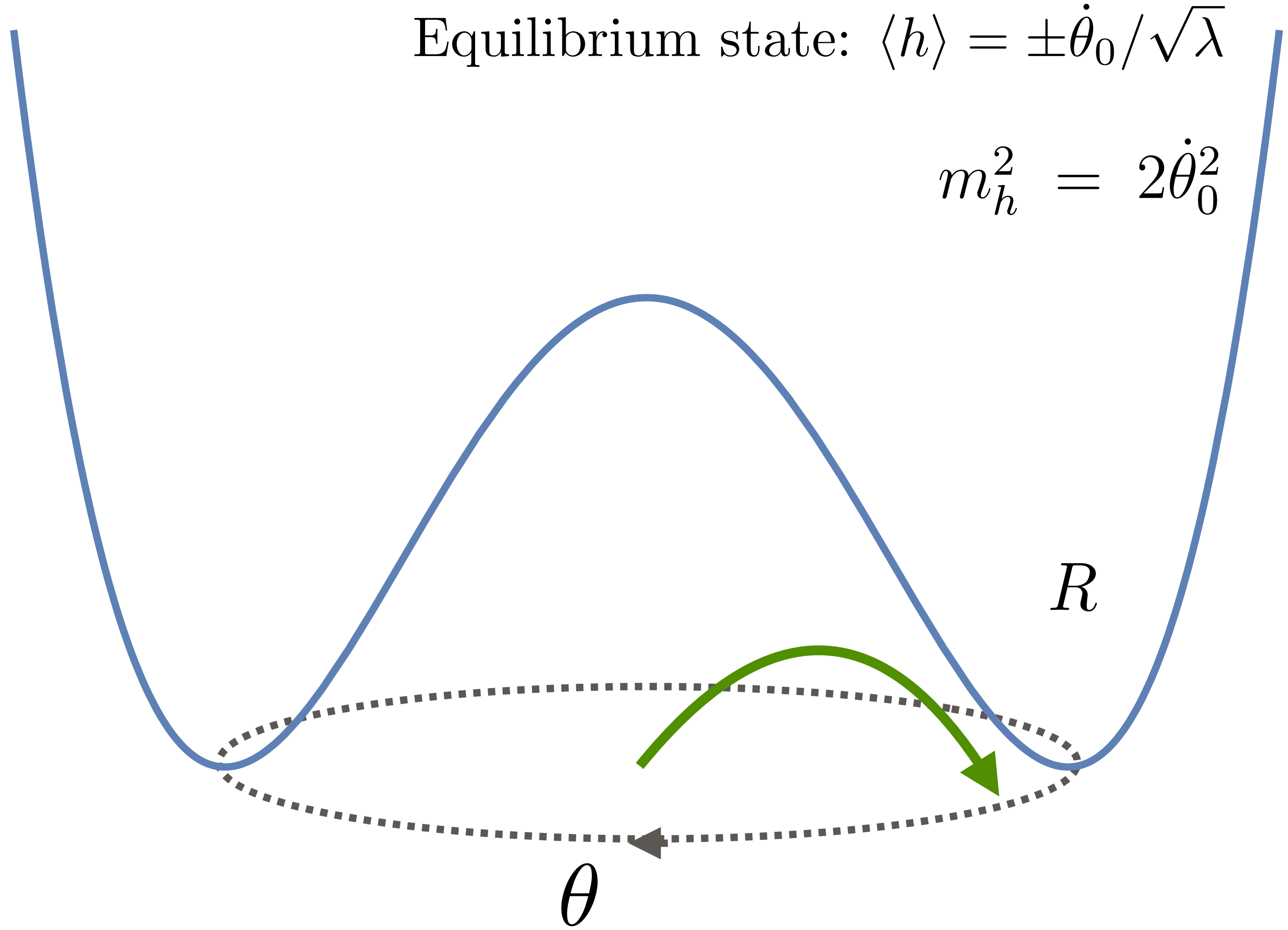
$$\Phi_H = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ h \end{pmatrix}$$

This work

Heavy-lifting from broken symmetry

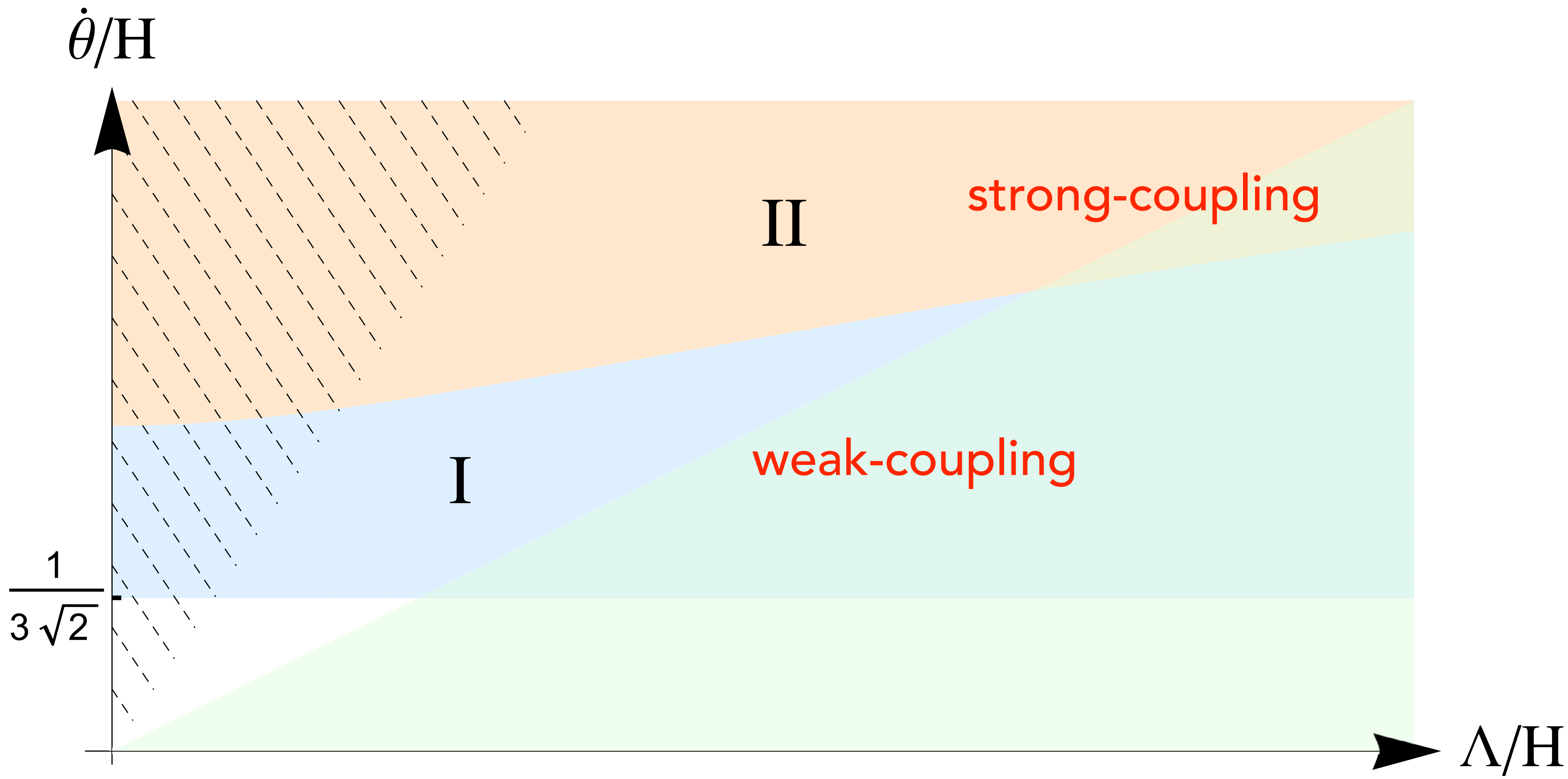
Equilibrium state: $\langle h \rangle = \pm \dot{\theta}_0 / \sqrt{\lambda}$

$$m_h^2 = 2\dot{\theta}_0^2$$



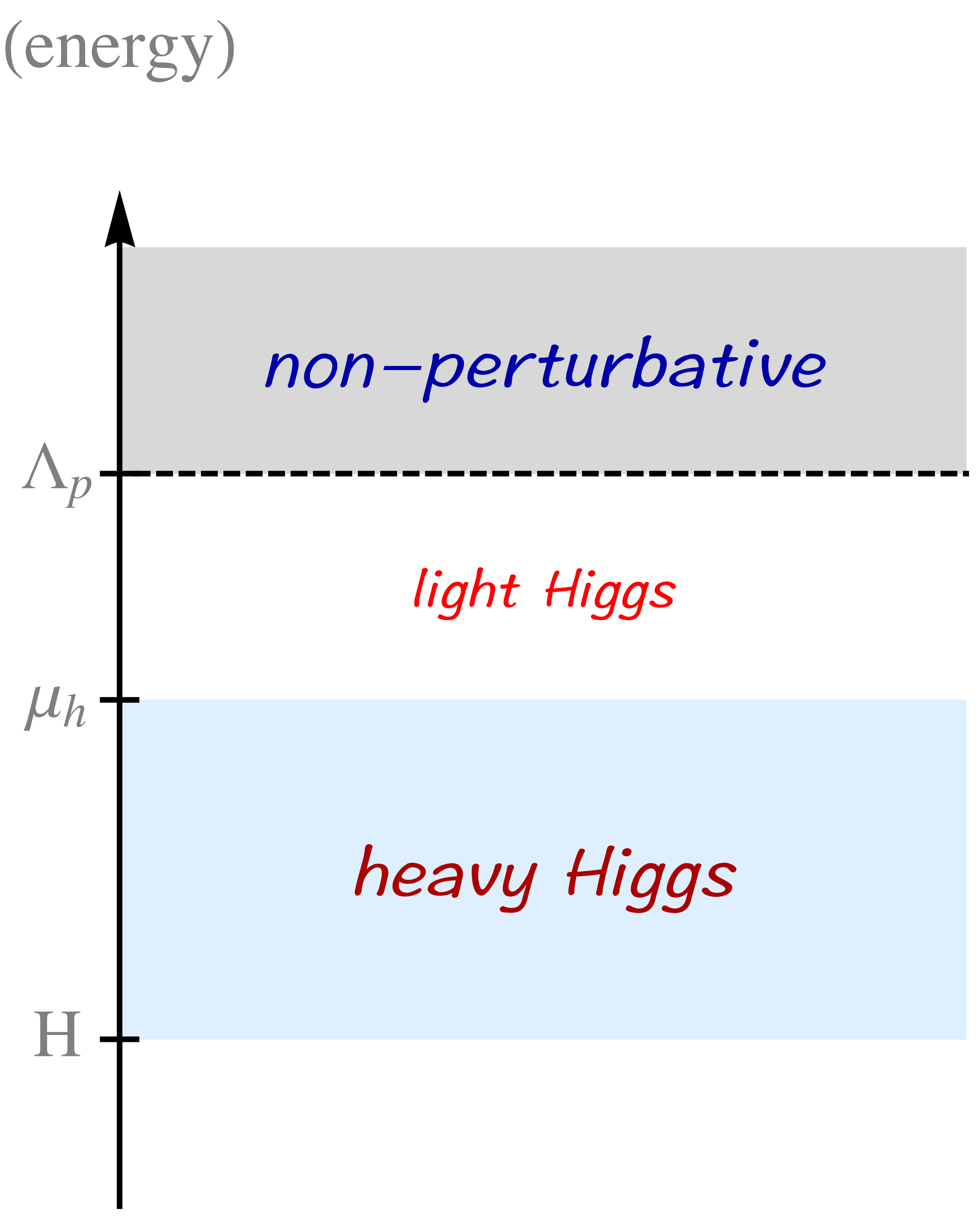
$R = (\Lambda^2 + h^2)^{1/2}$, $\qquad \theta = \phi/\Lambda$,

Heavy-lifting from broken symmetry



scale of heavy Higgs

$$\mu_h \equiv (m_h^2 + \mu^2)^{1/2} = m_h/c_h$$

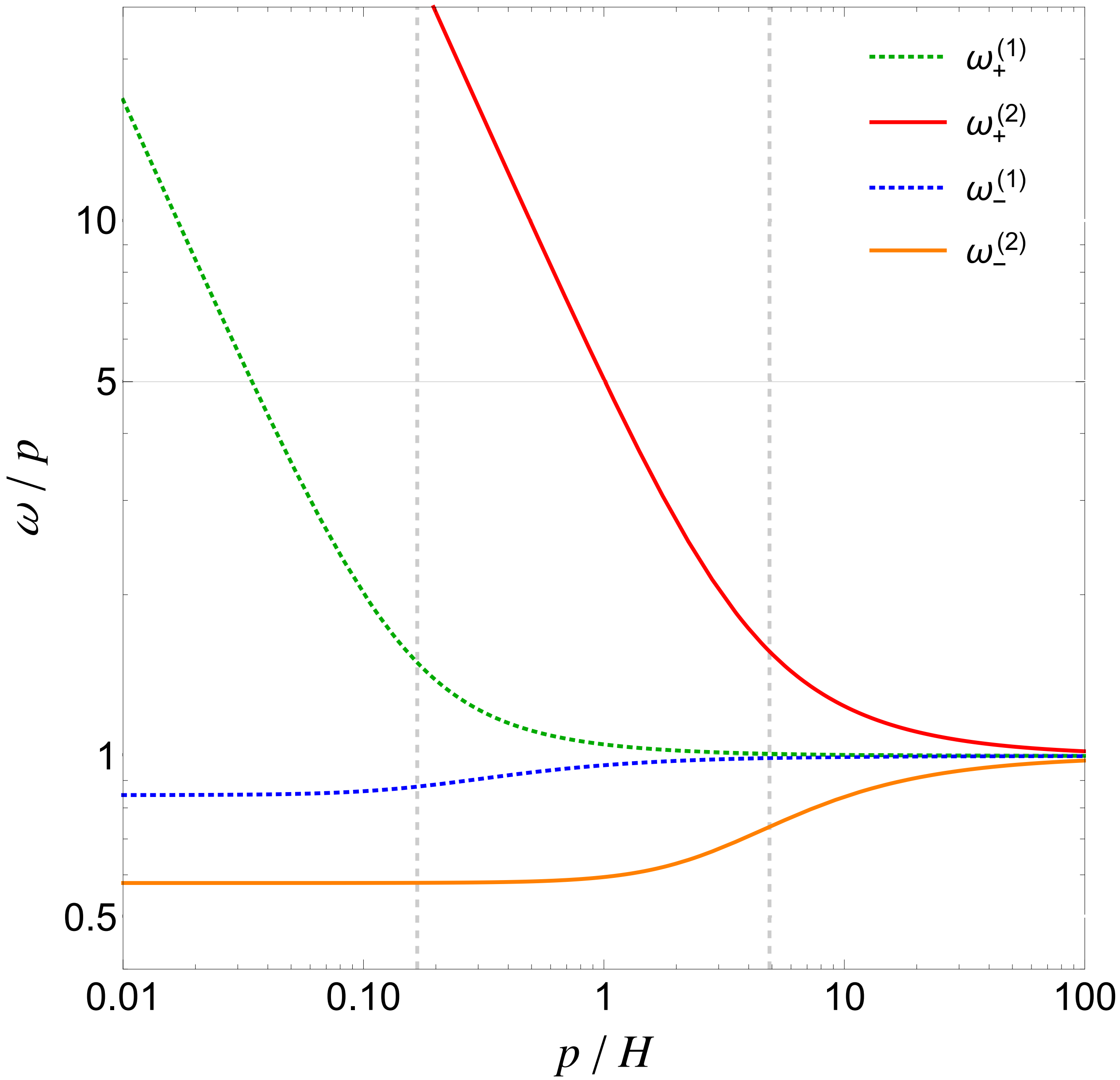


➤ strong-coupling does not necessarily violate perturbativity.

dispersion relations

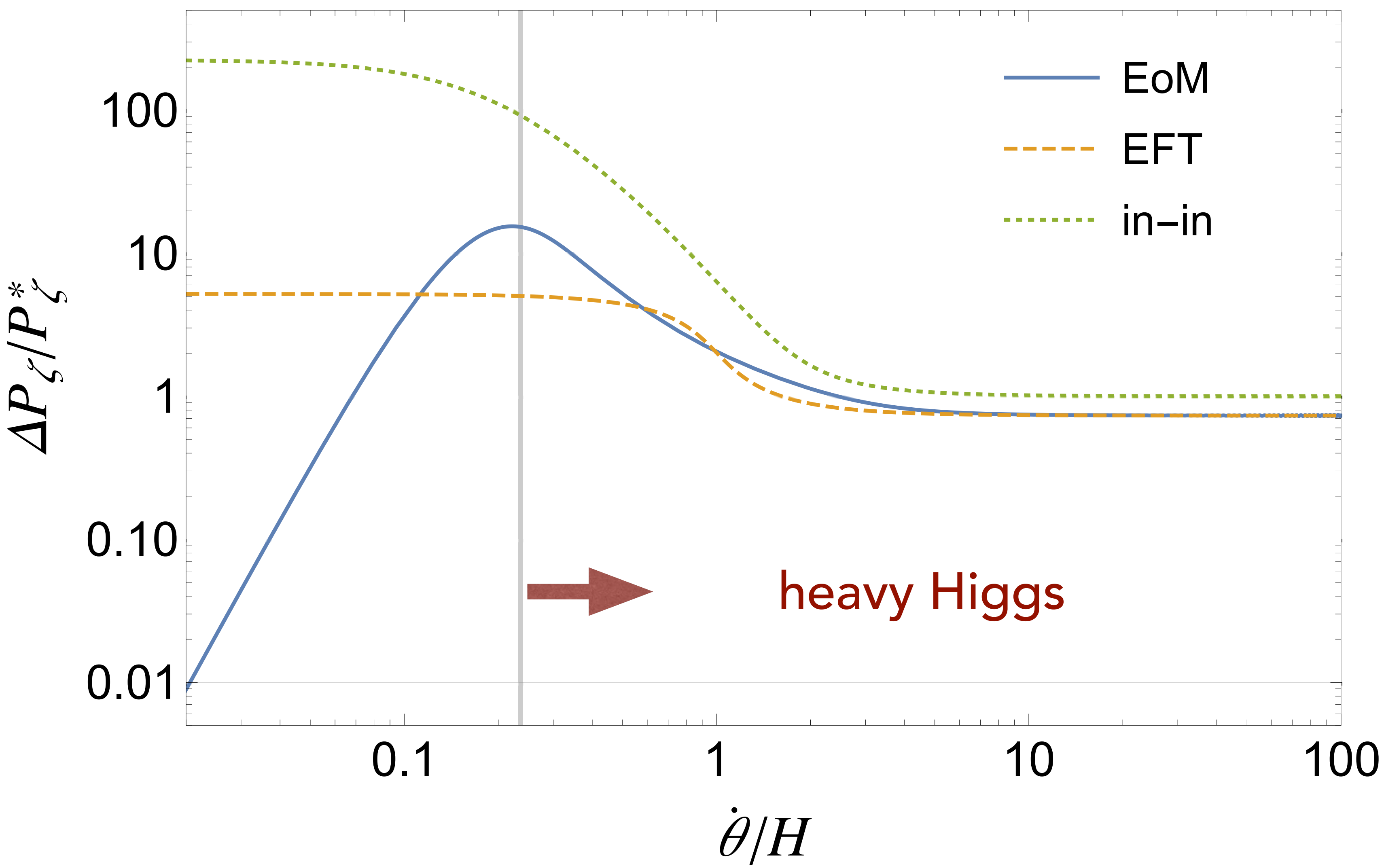
$(1) \quad \mu_h < H$

$(2) \quad \mu_h > H$



Power spectrum

ΔP_ζ : Higgs contribution to power spectrum

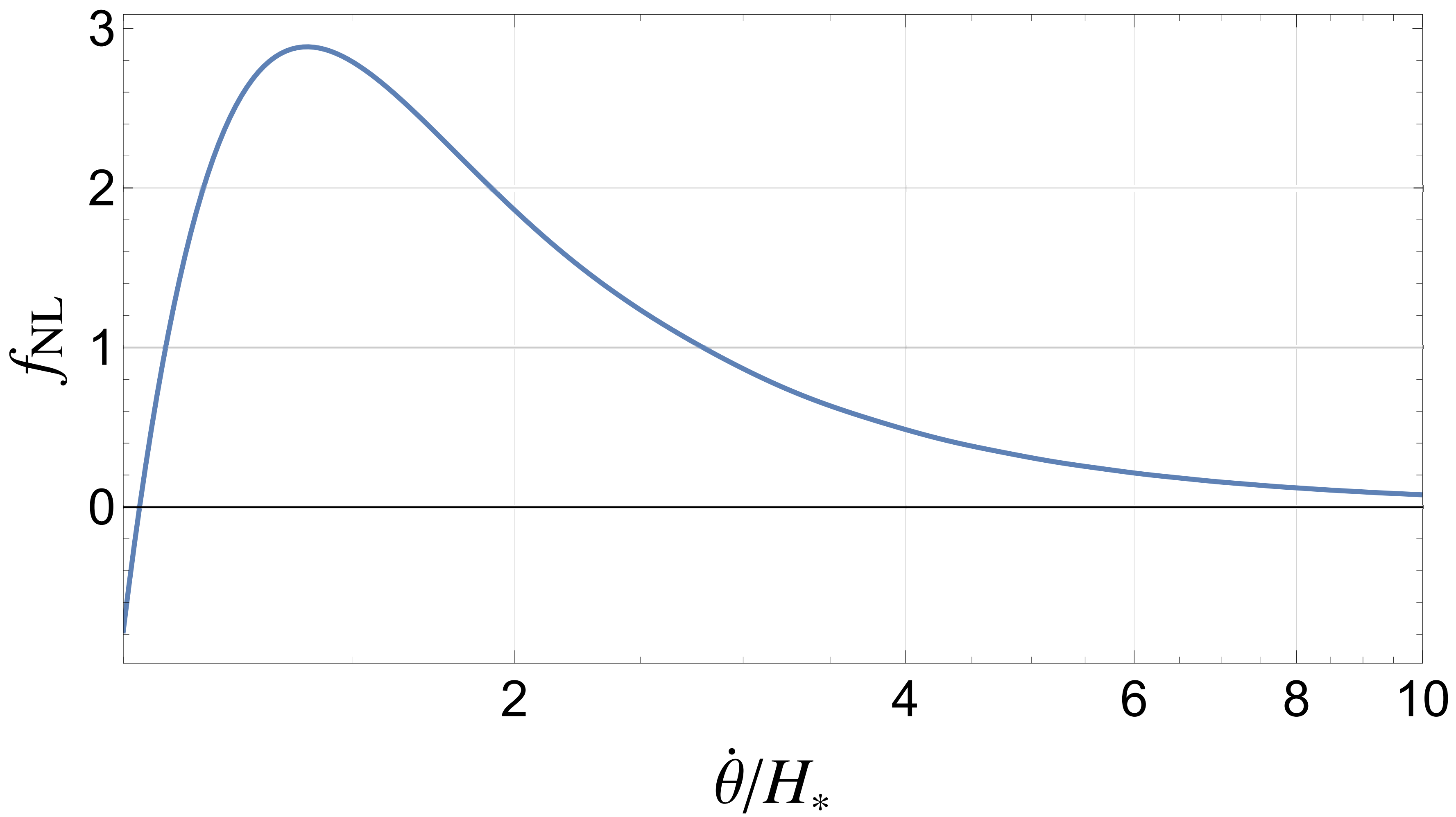


two-field inflation ⟷ **quasi-single field inflation**

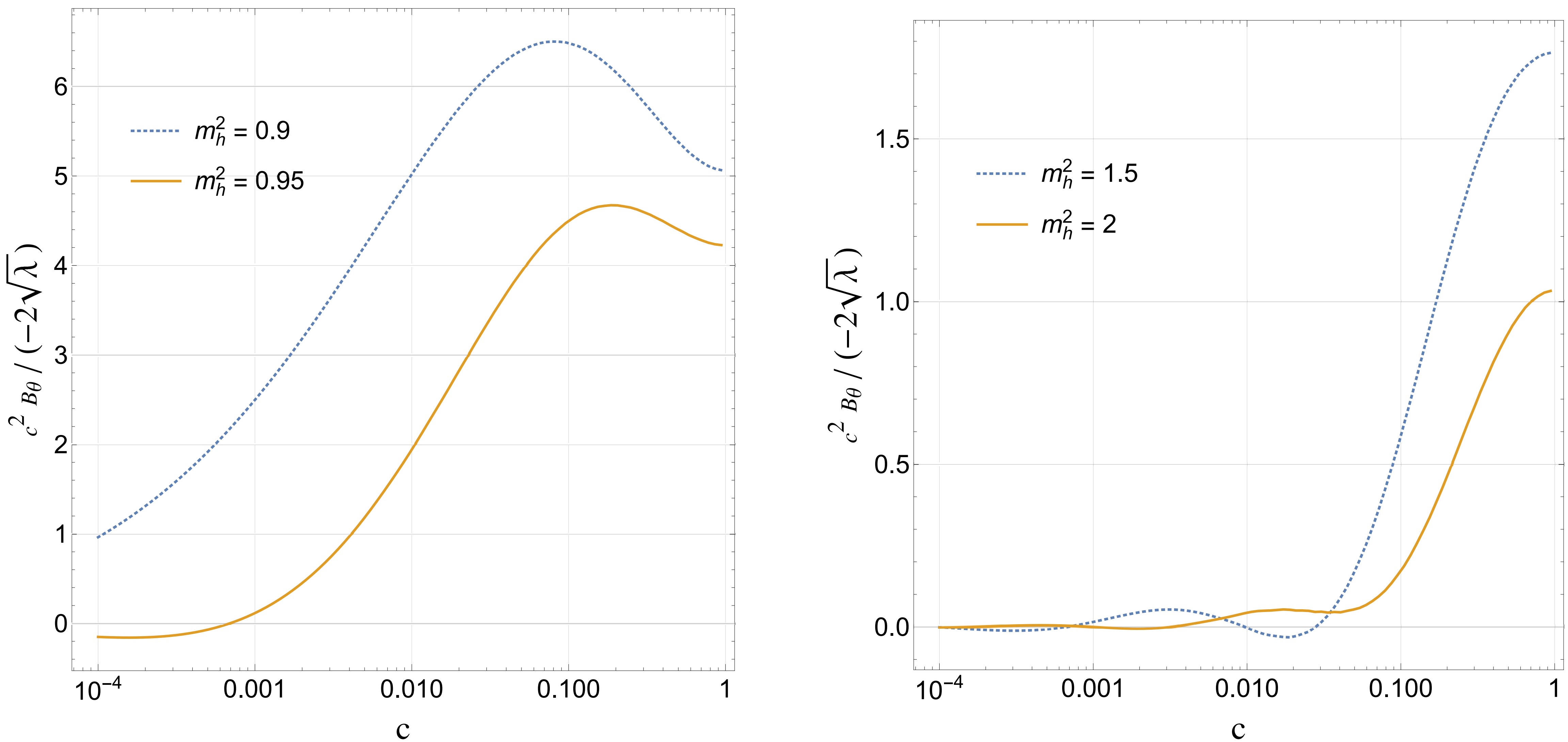
$c_h^2 \to 1$ $c_h^2 \to 1/3$

Bispectrum (equilateral limit)

$$k_1 = k_2 = k_3$$



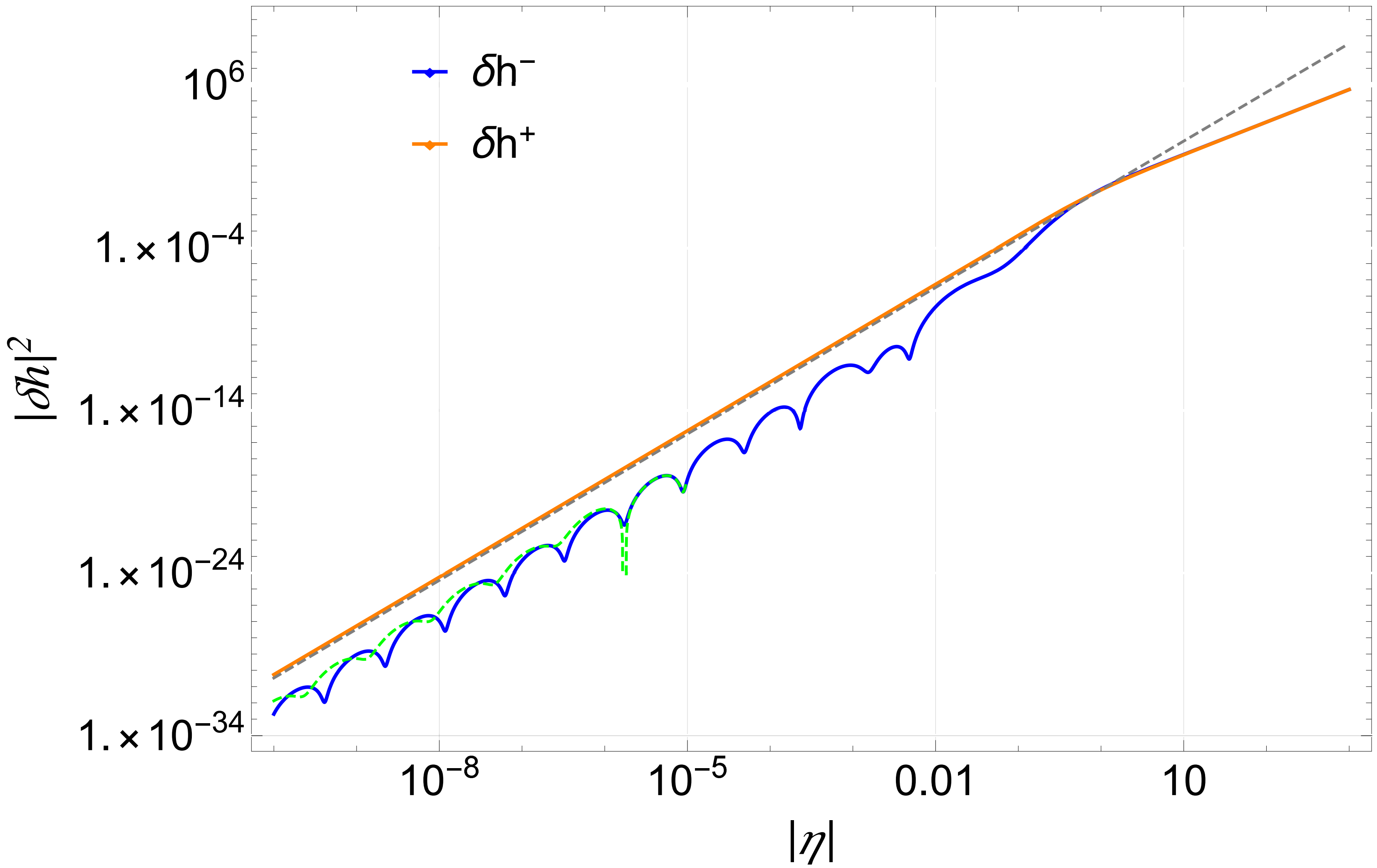
Bispectrum (from equilateral to squeezed) $k_1 = k_2 = ck_3$



shapes beyond single-field inflation

Heavy Higgs production

$$\delta h \sim \sum_i \hat{O}_i \, \eta^{\Delta_i}$$



the non-analytic scaling with strong-coupling:

$$L_h \to \sqrt{\frac{\mu_h^2}{H^2} - \frac{9}{4}} = \sqrt{\frac{m_h^2}{H^2 c_h^2} - \frac{9}{4}}$$

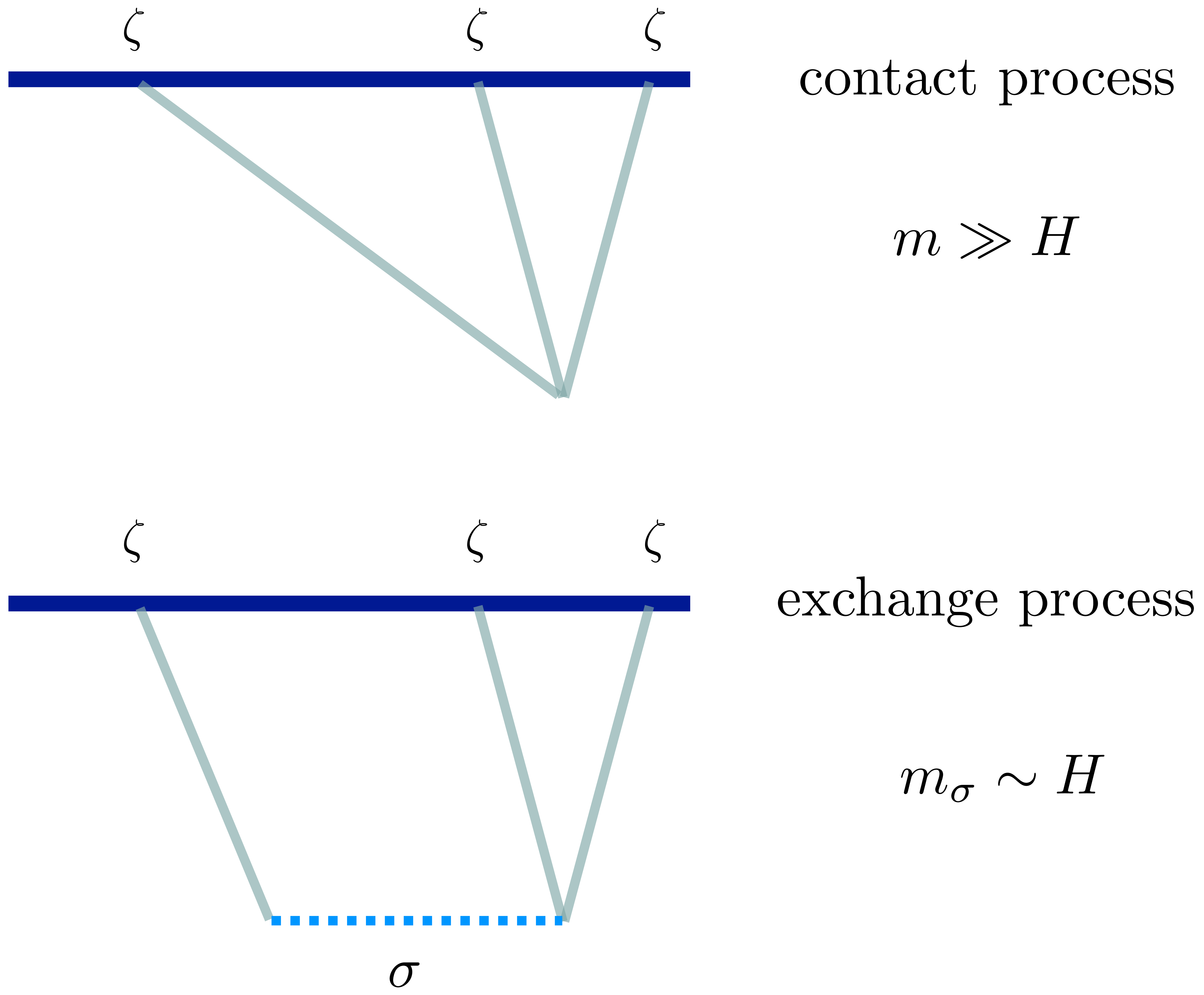
See also An et. al [1706.09971]
for three-point functions

REMARKS

and outlook

- Heavy particle production are encoded as non-analytic momentum scaling in primordial non-Gaussianity.
- SM particles can be observable in non-Gaussianity by heavy-lifting.
- Efficient particle production from spontaneous symmetry breaking and strong-couplings.
- Challenge for cosmological collider: SM signals or new physics?

$$L_h \rightarrow \sqrt{\frac{\mu_h^2}{H^2} - \frac{9}{4}} = \sqrt{\frac{m_h^2}{H^2 c_h^2} - \frac{9}{4}}$$



ζ ζ ζ
contact process
m ≫ H
ζ ζ ζ
exchange process
m_σ ∼ H
σ